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THE DYNAMIC SOIL-BUILDING INTERACTION AND THE REDUCTION OF INPUT MOTION OF CONTEMPORARY TIMBER HOUSES

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SUMMARY

This paper describes the dynamic soil-structure interaction of two storied contemporary timber houses and a five storied R/C structure based on earthquake observations. Comparison is made on the elongation ratio of natural period, amplification factors and the damping effect between two storied timber houses and a five storied R/C building. The main results are as follows;
The elongation ratio of natural period is about 2 to 8 % in the timber houses, on the other side, about 30 % in the R/C building. Judging from the maximum acceleration ratio of 1st floor to ground level, the reduction of input motion to timber houses is extremely small compared to the R/C building. Amplification factors of peak values obtained from the ratios of top floor to 1st floor in the timber houses are larger than that of the R/C building. The damping effect in the timber houses is very small compared to that of the R/C building. Consequently, it is not evident that the soil-building interaction effect could be taken into the structural design of timber houses because of the lack of data.

INTRODUCTION

The earthquake observations are carried out in many buildings for the sake of the earthquake resistant design. The accumulation of earthquake records in R/C or steel structures have made it possible to include the soil-building interaction effect into the earthquake resistant design.
While, it is very rare that seismometers are set in timber houses because of its expensiveness. Under these circumstances we started earthquake observation in timber houses from 2000, taking advantage of the development of micro seismometers [1]. After investigation of observed twenty five earthquakes, we don't get evident results because of the lack of data. Therefore, for the purpose of taking the soil-building interaction into the structural design, the earthquake observation at many type of soil and house should be carried out.

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OUTLINE OF TIMBER HOUSES, BUILDING, SOIL AND OBSERVED EARTHQUAKES

The observation sites exist in Utsunomiya-city. The outlines of the objective timber houses and R/C building are shown in Table1, and external appearances of these buildings are shown in Photo 1. The R/C building exists in the campus of Utsunomiya-University. The soil where this building stand on is consists of loam of about six meters thick on hard gravel as shown in Fig.1. The houses No.1 and 3 stands on the hard soil and house No.2 stands on the middle soil. The spectral ratio of microtremors on this soil in horizontal component to that in vertical component called H/V spectral ratios are shown in Fig2. From this figure, it is recognized that the predominant frequency of the soil is about 6.2 Hz. Seismometers of three components are set in these buildings of the top floor, first floor and on their subsoil. The details of seismometers are shown in Table 2. QDR are set in the timber houses and its subsoil and K2, Etna and QDR are set in the R/C building and its subsoil. The outlines of earthquakes observed at these houses are shown in Table 3. The epicenters of these earthquakes are shown in Fig.3.

Table 1 Outlines of timber houses

House No.	Foundation type	Material of exterior wall	Material of roof	Area of 1st floor (m^2)	Area of 2nd floor (m^2)	Total area (m^2)
1	mat	ALC	slate	87.0	82.0	169.0
2	mat	aluminum siding	tile	113.5	77.2	190.7
3	mat	mortar	tile	136.4	105.5	241.9

Photo 1 External appearance of house No.1, 2, 3 and R/C bldg. from left to right

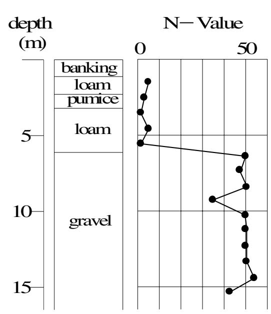

Fig.1 Soil profile where R/C bldg stand on

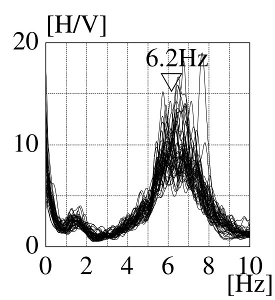

Fig.2 H/V spectral ratio of soil

Table 2 Details of seismometers

	K2	Etna	QDR
G.P.S.	built in	built in	--
resolution (bit)	19	18	11
full scale (±)	2G (variable)	2G (variable)	2G (H),1G (V)
memory media	memory card	memory card	flash memory
memory capacity	5MB (variable)	10MB (variable)	180KB
built in battery	36 hrs.	10 hrs.	1 hrs.
size (mm)	256x381x178	256x381x166	100x150x86
weight (kg)	11.4	9	1.4

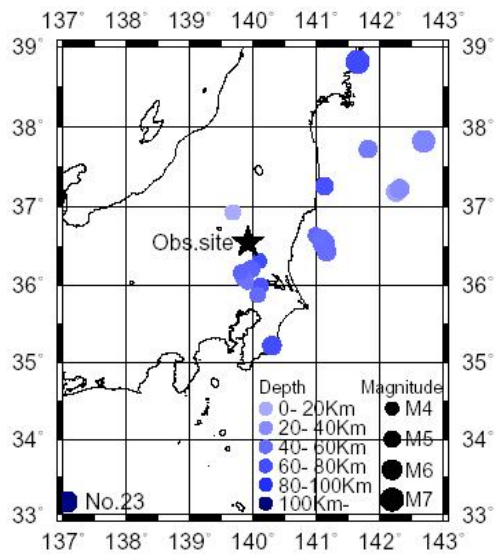

Fig. 3 Epicenters

Table 3 Outlines of observed earthquakes

Eq. No.	Epicenters						Recorded Earthquakes & its Intensities							
	Date	Time	Latitude	Longitude	Depth (km)	Mag.	House No. 1		House No. 2		House No. 3		R/C bldg.	
								I_{JMA}*		I_{JMA}*		I_{JMA}*		I_{JMA}*
1	2000/07/21	03:39	36.53N	141.12E	49.37	6.4			○	3.3			○	3.0
2	2000/10/18	12:58	36.93N	139.68E	9.18	4.7	○	1.3					○	1.8
3	2001/02/25	06:53	37.19N	142.26E	15.83	5.9	○	1.3	○	1.8			○	1.6
4	2001/03/06	14:32	36.64N	141.00E	51.98	4.7			○	1.4			○	1.7
5	2001/07/20	06:02	36.16N	139.82E	55.17	5.0			○	2.3			○	3.6
6	2001/07/26	03:33	36.05N	139.81E	82.88	4.2							○	1.8
7	2001/09/25	04:35	36.31N	140.10E	70.89	4.4	○	2.2	○	1.5			○	1.9
8	2001/09/25	04:57	36.31N	140.10E	71.22	4.4	○	2.4	○	1.5			○	2.4
9	2001/10/02	17:19	37.73N	141.82E	40.76	5.5			○	1.5			○	1.7
10	2001/10/18	06:30	36.08N	139.86E	49.02	4.4	○	2.9	○	1.6			○	2.6
11	2002/02/12	22:44	36.59N	141.09E	47.79	5.7	○	2.7					○	2.5
12	2002/06/14	11:42	36.21N	139.98E	56.99	5.1			○	3.0			○	4.0
13	2002/07/13	21:45	36.00N	140.13E	65.45	4.8	○	2.6	○	1.6			○	2.7
14	2002/07/24	05:05	37.23N	142.32E	30.00	5.9			○	1.8			○	1.6
15	2002/12/23	05:31	36.20N	139.99E	54.71	4.2	○	1.9					○	1.9
16	2003/03/13	12:12	36.09N	139.86E	47.26	5.0	○	4.1	○	2.8			○	3.7
17	2003/05/06	23:48	36.03N	139.91E	45.55	4.2			○	1.5			○	2.5
18	2003/05/12	00:59	35.87N	140.07E	49.92	4.6	○	2.2					○	1.9
19	2003/05/26	18:24	38.82N	141.65E	72.03	7.1	○	2.9	○	2.8			○	2.9
20	2003/05/31	02:47	36.17N	139.81E	54.54	4.0			○	1.4			○	1.7
21	2003/09/20	12:54	35.22N	140.30E	69.96	5.8			○	1.9			○	2.2
22	2003/10/31	10:06	37.83N	142.70E	33.35	6.8					○	1.7	○	1.9
23	2003/11/12	17:26	33.17N	137.06E	397.83	6.5	○	3.0	○	2.2	○	2.8	○	2.9
24	2003/11/15	03:43	36.43N	141.17E	48.4	5.8	○	2.3	○	2.1	○	2.2	○	2.2
25	2004/01/23	18:01	37.26N	141.13E	65.87	5.3			○	1.6				1.9

*I_{JMA}: calculated after the equation shown in the home page of Japan Meteorological Agency

SEISMIC WAVES, FOURIER SPECTRA AND ITS RATIOS

Taking one earthquake the epicenter of which is shown as Eq. No.23 in Fig.3 is recorded by all observation sites. Seismic waves observed at the top floor at each of the site are shown in Fig.4. Fourier spectra and its ratio of these waves of NS component are shown in Fig.5. In these figures, Fourier spectra are shown in the upper row and its ratios are shown in the lower row. From right side and lower row of this Fig., the peak frequency of solid line (Top/GL) decreases about 30% from that of dashed line (Top/Base). This decrease could be expressed to the elongation ratio of natural period, and caused by the effect of the soil-building interaction. By contrast, such decreases are hardly recognized in timber houses except house No.1. From this figure, the elongation ratio of natural period is about 30 % in the R/C building, and about 2 to 8 % in the timber houses.

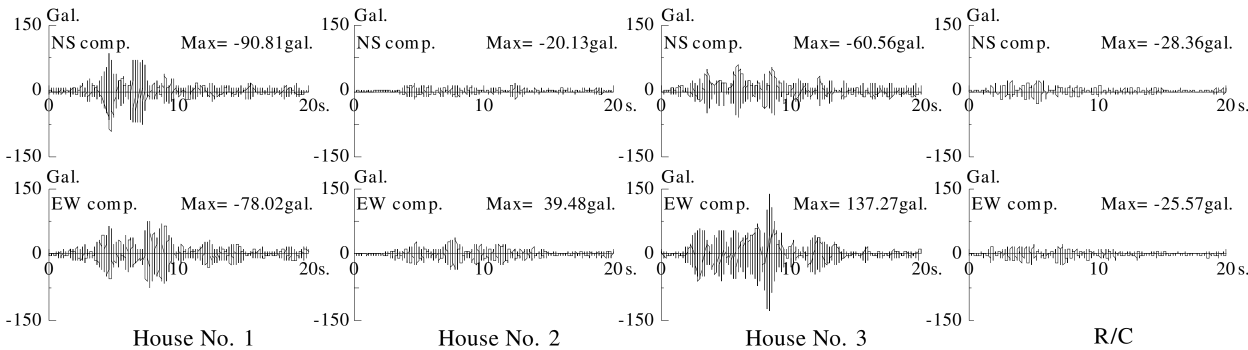

Fig.4 Seismic waves of Eq. No. 23 (2003.11.12)

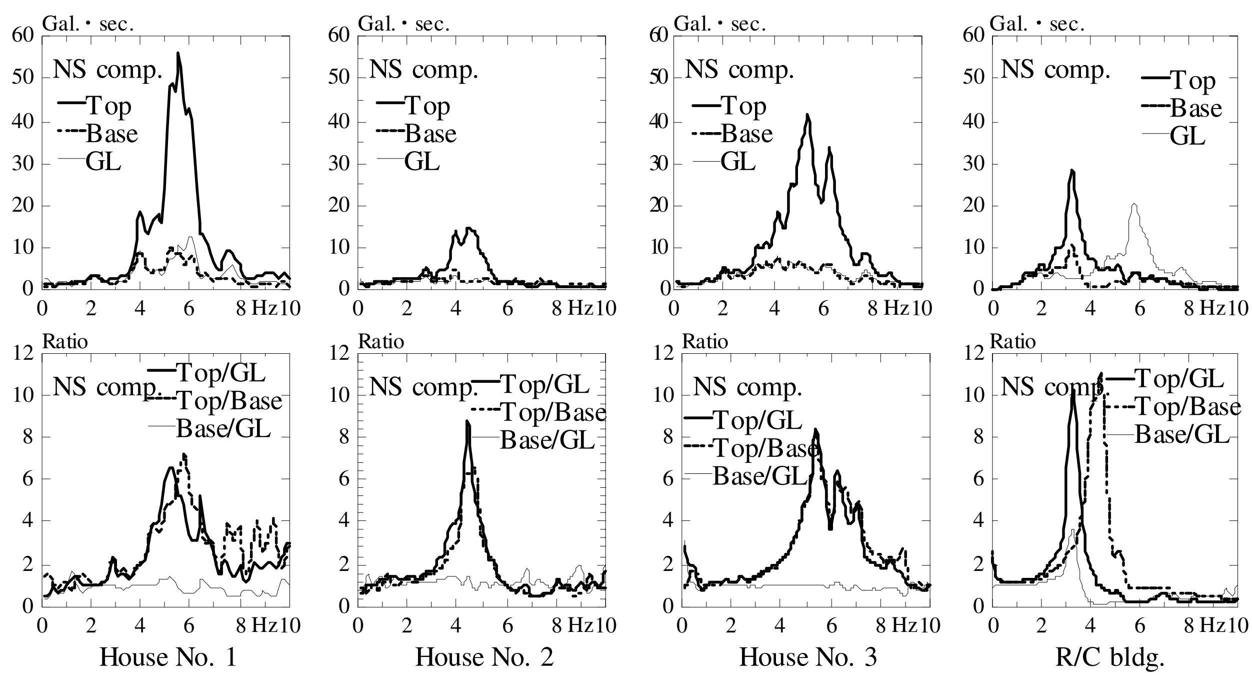

Fig.5 Fourier spectra and its ratios of Eq. No.23 of NS component

INVESTIGATION OF AMPLIFICATION FACTORS

We take our investigation into the relation between the amplification factors and the maximum acceleration at the ground level in the time domain and the frequency domain based on earthquakes already shown in the Table 2.

Investigation in time domain

First, in the time domain investigation, to obtain the general tendency of the amplification factor, Figs. 6 to 9 plot these amplification factors versus the maximum acceleration at the ground level or 1st floor level for each of the houses. The upper row of Figs. 6 to 9 shows the amplification factors of 1st floor to ground level. From Fig.9, in case of the R/C building these ratios are distributed from 0.2 to 1.0. While, from Fig. 6 (house No.1), these factors widely distribute from 0.4 to 2.3, and from Figs. 7 and 8 (house No. 2 and 3), these factors distribute around 1.0. These ratios less than 1.0 mean the reduction of the input motion to buildings. According to the above investigation, the reduction of input motion to timber houses is extremely small compared to the R/C building.

The lower row of the Figs. 6 to 9 shows the amplification factors of the top floor to the first floor. From Fig 9, the average of these factors is about 2.0 and distributed from 1.0 to 3.0. While, from Figs. 6 to 8 the averages of these factors are 3.0, 2.0 and 3.5 in house No. 1, 2 and 3, respectively. These larger ratios in the timber houses than that in the R/C building explain that the relative displacement of timber houses are larger than that of R/C building because of its semi-rigid joints. These plots show the tendency that the factors decrease gradually with the maximum acceleration, expect the house No.3.

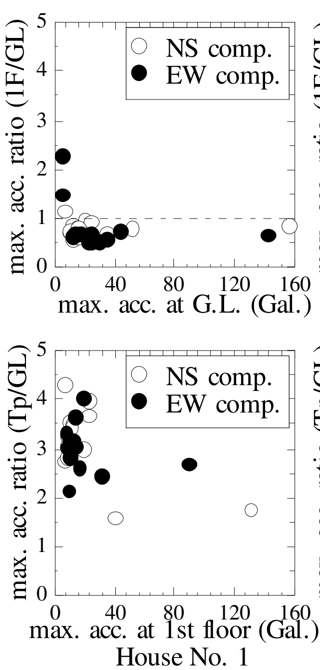

Fig. 6
Amplification factors
in time domain
(House No.1)

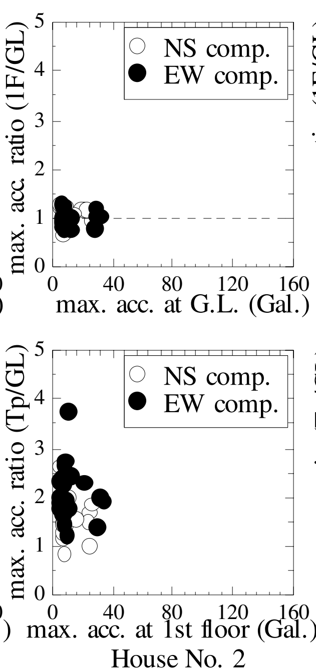

Fig.7
Amplification factors
in time domain
(House No.2)

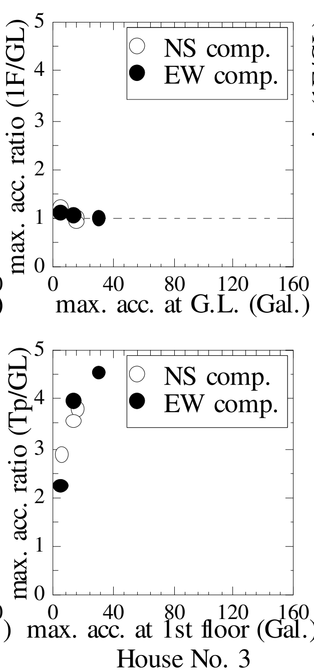

Fig. 8
Amplification factors
in time domain
(House No.3)

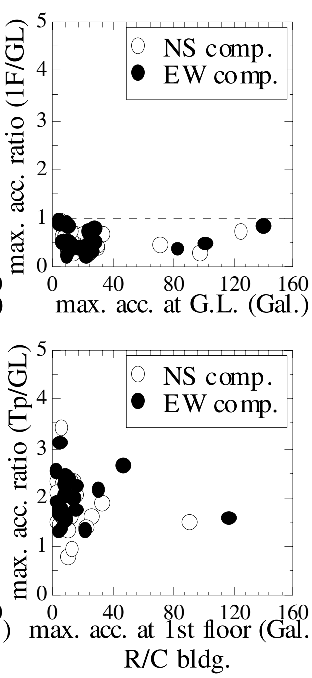

Fig.9
Amplification factors
in time domain
(R/C bldg.)

Investigation in frequency domain

Second, in the frequency domain investigation, Figs. 10 to 13 plot an amplification factors which obtained from the peak or valley values appeared in the spectral ratios versus maximum acceleration at the ground level. The upper, middle and lower row of the figures show the peak, valley values appeared in the spectral ratio of the 1st floor to ground level and the peak values appeared in the spectral ratio of the top floor to the 1st floor, respectively.

From the upper row of figures, the amplification factors in the R/C building and the timber houses distribute from 2.5 to 4.5 and from 0.5 to 2.5, respectively. From the middle row of figures, the amplification factors in the R/C building distribute around 0.1, while in the timber houses roughly distributed from 0.5 to 1.0 expect small seismic waves under 10 Gal at the ground level. This factor is almost equivalent to the damping effect [1]. Therefore, in the timber houses the damping effect is very small compared to the R/C building. From the lower row of figures, the factors distribute from 5.0 to 10.0, and tend to decrease with the maximum acceleration at the ground level [2].

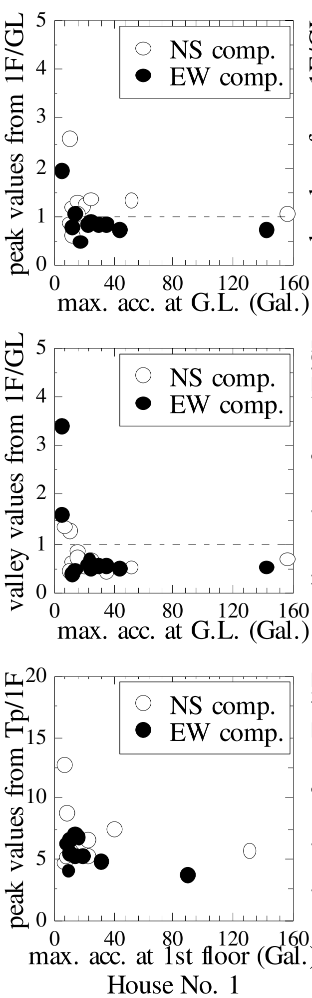

Fig. 10
Amplification factors
in frequency domain
(House No.1)

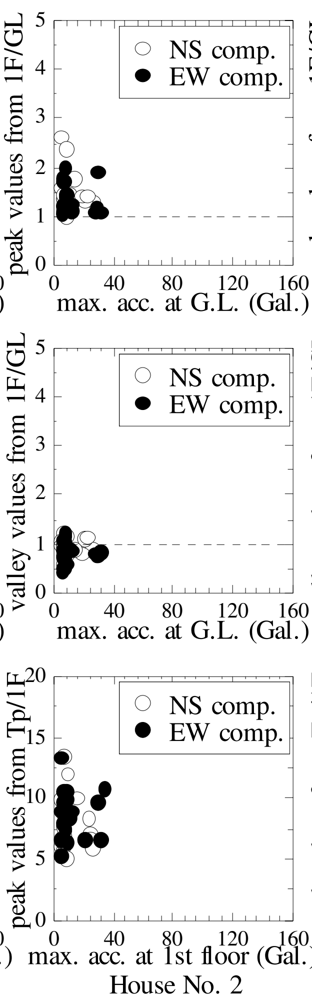

Fig. 11
Amplification factors
in frequency domain
(House No.2)

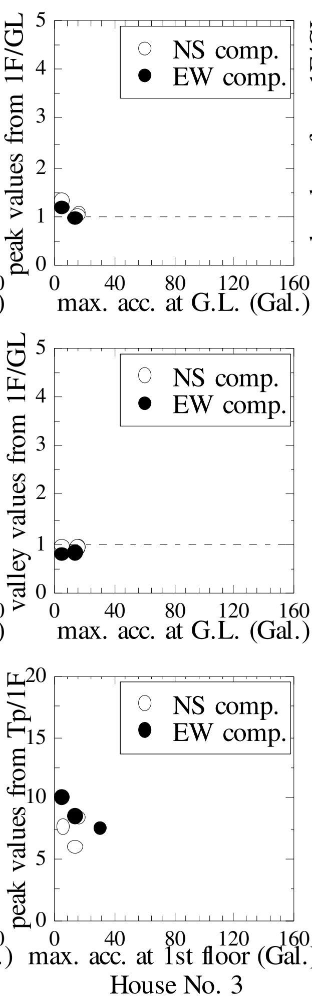

Fig. 12
Amplification factors
in frequency domain
(House No.3)

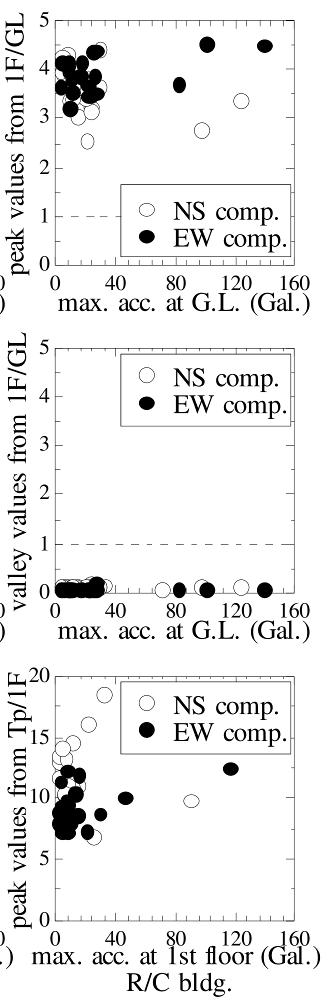

Fig. 13
Amplification factors
in frequency domain
(R/C bldg.)

RESULTS

Main results obtained from the earthquake observation of the three timber houses and the R/C building are as follows;

1. The elongation ratio of natural period is about 2 to 8 % in the timber houses, on the other side, about 30 % in the R/C building.
2. Judging from the maximum acceleration ratio of 1st floor to ground level, the reduction of input motion to timber houses is extremely small compared to the R/C building.
3. Amplification factors of peak values obtained from the ratios of top floor to 1st floor in the timber houses are larger than that of the R/C building. This explains that the relative displacement of the timber houses is larger than that of the R/C building.
4. The damping effect in the timber houses is very small compared to that of the R/C building.

Consequently, it is not evident that the soil-building interaction effect could be taken into the structural design of timber houses because of the lack of data. Therefore, for the purpose of taking the soil-building interaction into the structural design, the earthquake observation at many type of soil and house should be carried out.

REFERENCES

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